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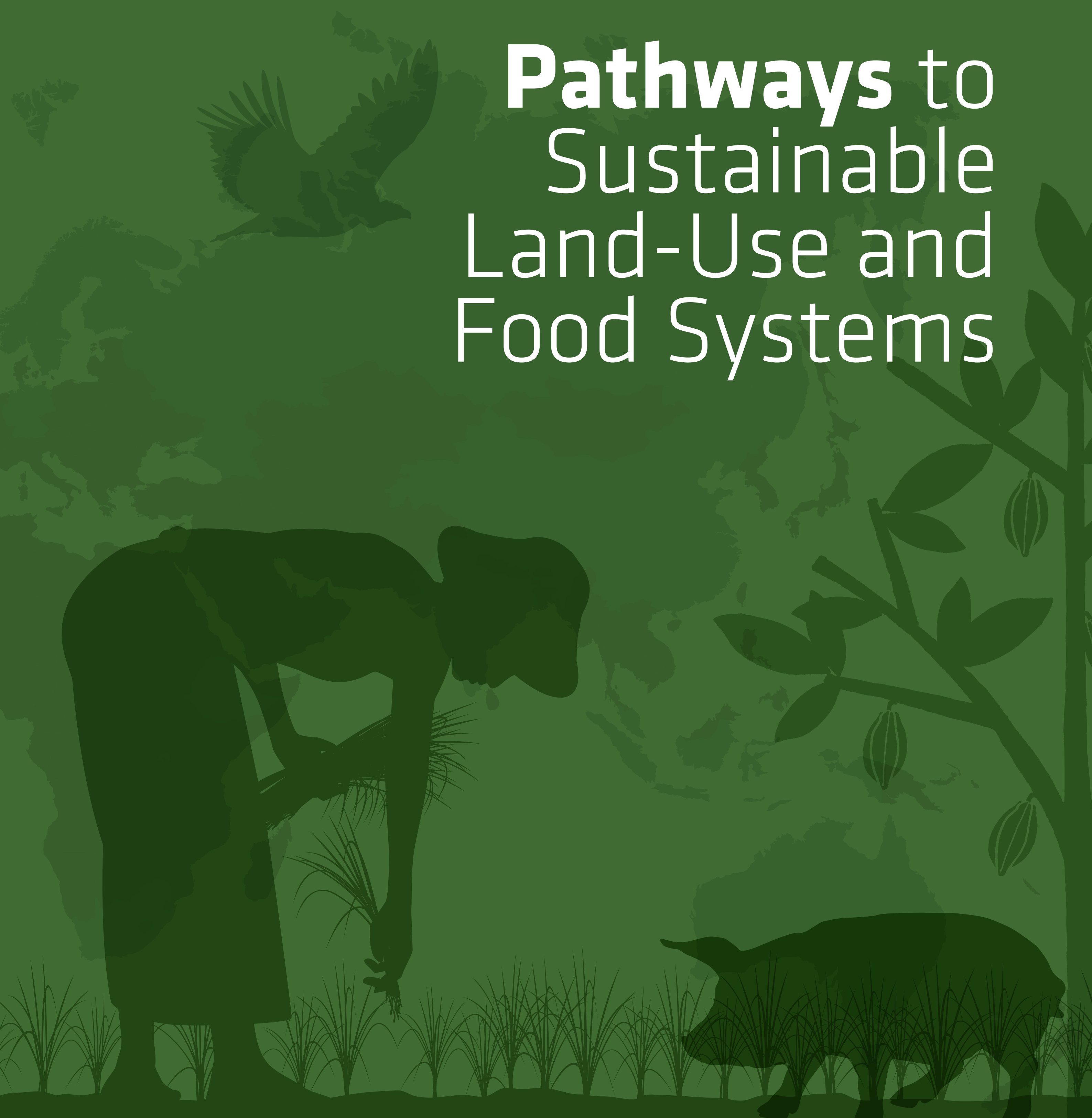
The Food and Land Use Coalition

2020 Report of the FABLE Consortium

Pathways to Sustainable Land-Use and Food Systems



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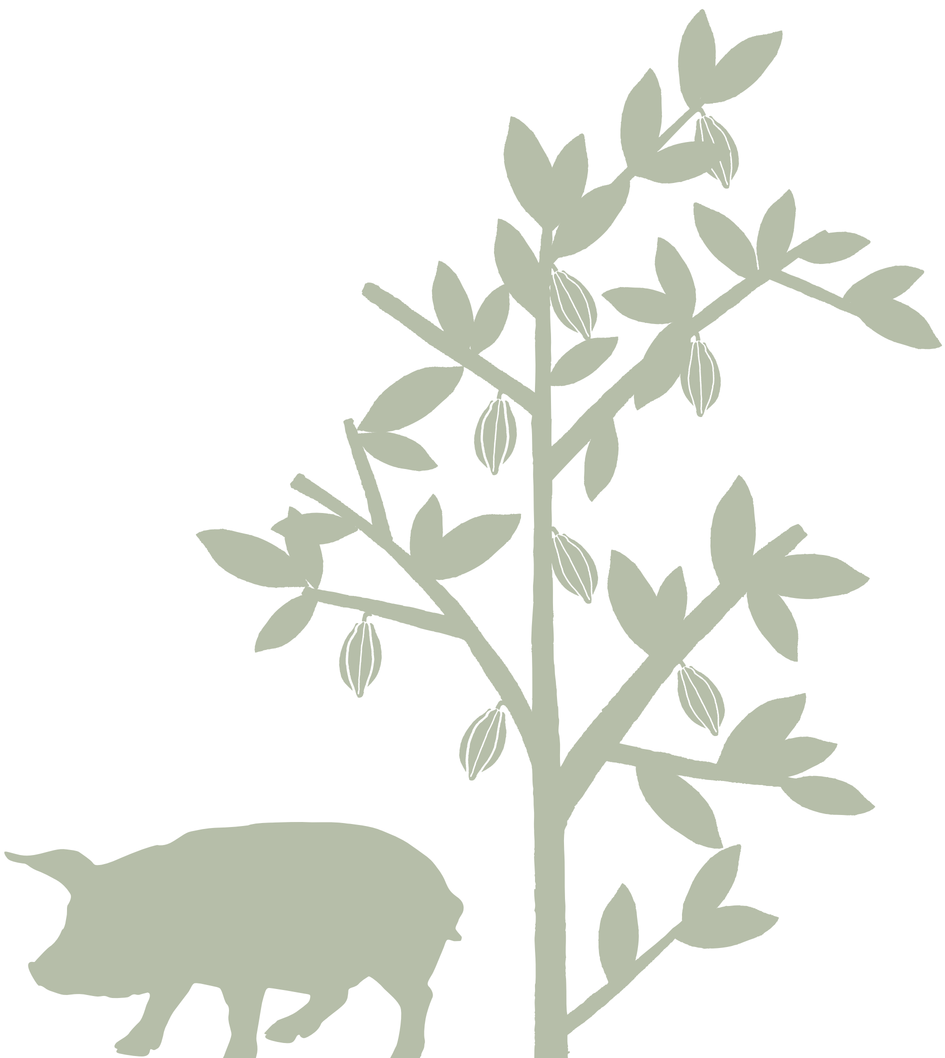
2020 Report of the FABLE Consortium

Pathways to Sustainable Land-Use and Food Systems in Mexico by 2050



Mexico

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This chapter of the 2020 Report of the FABLE Consortium *Pathways to Sustainable Land-Use and Food Systems* outlines how sustainable food and land-use systems can contribute to raising climate ambition, aligning climate mitigation and biodiversity protection policies, and achieving other sustainable development priorities in Mexico. It presents two pathways for food and land-use systems for the period 2020-2050: Current Trends and Sustainable. These pathways examine the trade-offs between achieving the FABLE Targets under limited land availability and constraints to balance supply and demand at national and global levels. We developed these pathways in consultation with national stakeholders and experts, including from the National Institute of Health (INSP) and the Department of Agriculture and Rural Development (SADER), and modeled them with the FABLE Calculator (Mosnier, Penescu, Thomson, and Perez-Guzman, 2019). See Annex 1 for more details on the adaptation of the model to the national context.

Climate and Biodiversity Strategies and Current Commitments

Countries are expected to renew and revise their climate and biodiversity commitments ahead of the 26th session of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) and the 15th COP to the United Nations Convention on Biological Diversity (CBD). Agriculture, land-use, and other dimensions of the FABLE analysis are key drivers of both greenhouse gas (GHG) emissions and biodiversity loss and offer critical adaptation opportunities. Similarly, nature-based solutions, such as reforestation and carbon sequestration, can meet up to a third of the emission reduction needs for the Paris Agreement (Roe et al., 2019). Countries' biodiversity and climate strategies under the two Conventions should therefore develop integrated and coherent policies that cut across these domains, in particular through land-use planning which accounts for spatial heterogeneity.

Table 1 summarizes how Mexico's Nationally Determined Contribution (NDC) (Gobierno de México, 2015), Long-Term Low Emissions and Development Strategy (LT-LEDS) (SEMARNAT 2016) treat the FABLE domains. According to the LT-LEDS, Mexico has committed to reducing its GHG emissions by 50% by 2050 compared to 2013. This does include emission reduction efforts from agriculture, forestry, and other land use (AFOLU). Envisaged mitigation measures from agriculture and land-use change include encouraging agriculture practices that preserve and increase carbon capture in soil and biomass (conservation cultivation and productive reconversion), changing livestock and forestry production (silvo-pasture and agroforestry systems), and strengthening forest monitoring to avoid illegal logging and forest fires (SEMARNAT, 2016). Under its current commitments to the UNFCCC, Mexico mentions biodiversity conservation.

Table 1 | Summary of the mitigation target, sectoral coverage, and references to biodiversity and spatially-explicit planning in current NDC and LT-LEDS

	Total GHG Mitigation					Mitigation Measures Related to AFOLU (Y/N)	Mention of Biodiversity (Y/N)	Inclusion of Actionable Maps for Land-Use Planning[1] (Y/N)	Links to Other FABLE Targets
	Baseline		Mitigation target		Sectors included				
	Year	GHG emissions (Mt CO_2e/yr)	Year	Target					
NDC (2016)	2013	665	2030	40% reduction	Energy, industrial processes, agriculture, land-use change and forestry, and waste	Y	Y	N	Water and deforestation, GHG emissions
LT-LEDS (2016)	2013	665	2050	50% reduction	Energy, industrial processes, agriculture, land-use change and forestry, and waste	N/A	N/A	N/A	Water and deforestation, GHG emissions

Note. "Total GHG Mitigation" and "Mitigation Measures Related to AFOLU" columns are adapted from IGES NDC Database (Hattori, 2019)
Source: Gobierno de Mexico (2015) for the NDC and SEMARNAT (2016) for the LT-LEDS

1 We follow the United Nations Development Programme definition, "maps that provide information that allowed planners to take action" (Cadena et al., 2019).

Table 2 provides an overview of the targets included in the latest National Biodiversity Strategies and Action Plan (NBSAP) from 2016, as listed on the CBD website (CBD, 2020), which are related to at least nine of the FABLE Targets related to agriculture and climate change. In comparison with FABLE Targets, Mexico's NBSAP targets have a more ambitious timetable. While they share the same principles, the NBSAPs intend to broaden the understanding and appreciation of biodiversity within and across sectors, and at all government levels, to ensure the continued provision of ecosystem services necessary for the well-being of the Mexican people (CONABIO, 2016).

Table 2 | Overview of the NBSAP targets in relation to FABLE targets

NBSAP Target	FABLE Target
(2.2) **Strategies are in place to integrate biodiversity in the following sectors: agriculture, forestry, fisheries, and tourism.**	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate
(4.2) **By 2030 Mexico counts with watersheds and aquifers in equilibrium, with an integrated and sustainable management of water.**	**WATER:** Blue water use for irrigation <2453 km^3yr^{-1}
(5.1) **By 2020, the rate loss of all habitats will maintain a decreasing trend and degradation-fragmentation will significantly be reduced.**	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate
(5.2) **By 2030 the decreasing trend in habitat loss and degradation will be close to zero in protected habitats.**	**BIODIVERSITY:** At least 30% of global terrestrial areas protected by 2030
(7.2) **By 2030, the efficient and sustainable use of water will spread significantly on the agricultural area.**	**WATER:** Blue water use for irrigation <2453 km^3yr^{-1}
(7.6) **By 2020, the forest ecosystems that are susceptible to exploitation will be used in a sustainable way and the integrated management of the landscape will be promoted while maintaining their connectivity, as well as their environmental services and biodiversity.**	**DEFORESTATION:** Zero net deforestation from 2030 onwards
(7.7) **By 2020, forest plantation areas with native species will increase in degraded sites and without incentivizing the loss of natural habitat.**	**DEFORESTATION:** Zero net deforestation from 2030 onwards
(11.1) **By 2020, at least 17 percent on land areas [...] will be conserved and managed efficiently and equitably through protected natural areas and other conservation instruments (biological corridors, Environmental Conservation Units, community conservation areas, areas voluntarily designated for conservation), while promoting their connectivity, landscape integrity and the continuity of environmental services provided.**	**BIODIVERSITY:** At least 30% of global terrestrial areas protected by 2030
(15.1) **By 2020, the ecosystem's resilience will be maintained and increased, through the conservation of biodiversity, prevention and reduction of threats and impacts that deteriorate and fragment them.**	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate
(15.2) **By 2030, at least 15 percent of degraded ecosystems will be restored, contributing to climate change mitigation, adaptation, resilience, and the fight against desertification.**	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate

Brief Description of National Pathways

Among possible futures, we present two alternative pathways for reaching sustainable objectives, in line with the FABLE Targets, for food and land-use systems in Mexico.

Our Current Trends Pathway corresponds to the lower boundary of feasible action. It is characterized by low population growth (from 128 million in 2020 to 148 million in 2050) (CONAPO, 2018), significant constraints on agricultural expansion, a low afforestation target, a 18% increase in the extent of protected areas, the same productivity growth as over 2000 – 2010 for livestock (SIAP, 2020) and an evolution in diets similar to the trends between 2000 - 2010 (high in cereals and sugar, increased intake in oils and fats, roots, nuts and red meat) combined with low physical activity, increased exports and imports compared to 2010 (see Annex 2). This corresponds to a future based on current policy and historical trends that would also see considerable progress with regards to halting agricultural expansion and a reconversion of cropland towards cultivation of high value exports (SAGARPA, 2017). Moreover, as with all FABLE country teams, we embed this Current Trends Pathway in a global GHG concentration trajectory that would lead to a radiative forcing level of 6 W/m^2 (RCP 6.0), or a global mean warming increase likely between 2°C and 3°C above pre-industrial temperatures, by 2100. Our model includes the corresponding climate change impacts on crop yields by 2050 for maize, rice, wheat, and soybeans (see Annex 2).

Our Sustainable Pathway represents a future in which significant efforts are made to adopt sustainable policies and practices and corresponds to a high boundary of feasible action. Compared to the Current Trends Pathway, we assume that this future would lead to improved diets that rely less on cereals and more on high intake of fruits, vegetables, and pulses as well as animal protein in healthy quantities, a high afforestation target, 30% of the total land covered by protected areas, and no expansion of agricultural area along with high productivity levels for crops and (a relative increase of 48% for) livestock (see Annex 2). This corresponds to a future based mostly on the implementation of current and ambitious public policies, and national and international commitments in areas of biodiversity use and management, food production and land use. Mexico has a strong and ambitious General Law on Climate Change and a multitude of public policies specifically designed to mitigate and reduce the negative effects generated on the environment by its food and land use systems. It has also signed international agreements to protect its biodiversity and reduce its GHG emissions. In the Sustainable Pathway we have incorporated some of the existing public policies and international commitments to assess their impact on our model. With the other FABLE country teams, we embed this Sustainable Pathway in a global GHG concentration trajectory that would lead to a lower radiative forcing level of 2.6 W/m^2 by 2100 (RCP 2.6), in line with limiting warming to 2°C.

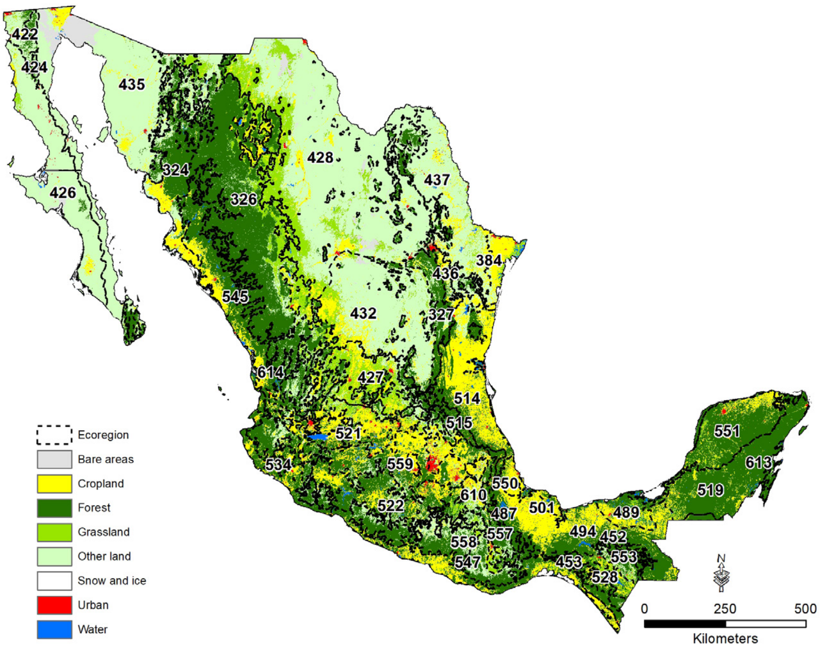
Land and Biodiversity

Current State

In 2010, Mexico was covered by 13% cropland, 41% pasture areas (mainly including induced pastures and semiarid scrubland), 34% forest, 1% urban, and 12% other natural land. Most of agricultural areas are located in the center of the country, the Gulf of Mexico coasts, and the central and southern part of the Pacific coast (Map 1). Temperate forests can be found along the mountain ranges that run along the country from the northeast to the southeast and from the northwest to the southwest, as well as the transversal mountain ranges in the south. Tropical vegetation is distributed along the coasts either in the form of tropical dry forests or tropical humid forest. The arid- to semiarid-lands climate zones are located in the north and represent more than 40% of the country. Other natural land is distributed across the country. The main threat to biodiversity is severe and non-regulated land-use change due to public policies that promote and incentivize agriculture expansion for the production of export crops (berries, avocados, soy and sugar cane), agricultural incentives for smallholders to alleviate poverty, and free-range cattle that roam across natural areas without restriction. Collateral effects of land-use change for agricultural practices include pollution and degradation of agricultural lands and surrounding areas.

We estimate that land where natural processes predominate[2] accounted for 28% of Mexico's terrestrial land area in 2010. In relative terms, the 453-Chimalapas montane forests holds the greatest share of land where natural processes predominate, followed by 487-Oaxacan montane forests, and 424-California montane chaparral and woodlands (Annex 4). Across the country, while 28 Mha (14%) of land is under formal protection, falling short of the

Map 1 | Land cover by aggregated land cover types in 2010 and ecoregions



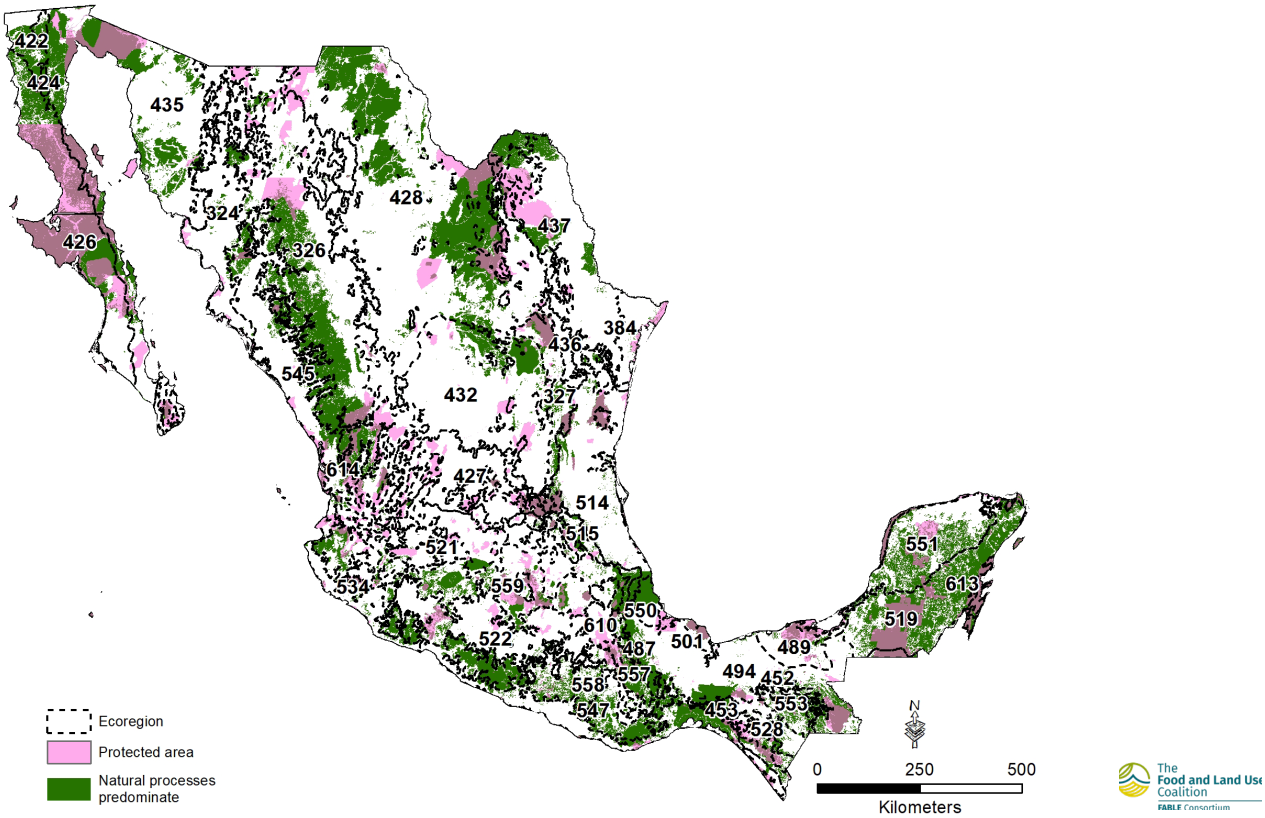
Sources. countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); land cover – ESA CCI land cover 2015 (ESA, 2017) Notes. Correspondence between original ESA CCI land cover classes and aggregated land cover classes displayed on the map can be found in Annex 3.

2 We follow Jacobson, Riggio, Tait, and Baillie (2019) definition: "Landscapes that currently have low human density and impacts and are not primarily managed for human needs. These are areas where natural processes predominate, but are not necessarily places with intact natural vegetation, ecosystem processes or faunal assemblages".

30% zero-draft CBD post-2020 target, only 26% of land where natural processes predominate, including biodiversity hot-spots, is formally protected. This indicates that only areas with abrupt topography and in Mexico's arid north (both important due to high levels of endemism) are likely to continue to experience low levels of transformation, although water availability in specific dryland spots has been used for agriculture (e.g. cereals, tomatoes, and alfalfa) causing their disappearance and the exhaustion of aquifers. On the other hand, tropical humid, dry, and temperate forest are at risk without enough actions to better protect them.

Approximately 41% of Mexico's cropland was in landscapes with at least 10% natural vegetation in 2020 (Map 2). These relatively biodiversity-friendly croplands are most widespread in 511-Yucatán dry forests followed by 519-Yucatán moist forests and 547-Southern Pacific dry forests. The regional differences in extent of biodiversity-friendly cropland can be explained by regional long-term production practices that promote the regeneration of the natural vegetation. The secondary vegetation in the Yucatan Peninsula is a result of these practices.

Map 2 | Land where natural processes predominated in 2010, protected areas and ecoregions



Note. Protected areas are set at 50% transparency, so on this map dark purple indicates where areas under protection and where natural processes predominate overlap.
Sources. countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); protected areas – UNEP-WCMC and IUCN (2020); natural processes predominate comprises key biodiversity areas – BirdLife International (2019), intact forest landscapes in 2016 – Potapov et al. (2016), and low impact areas – Jacobson et al. (2019)

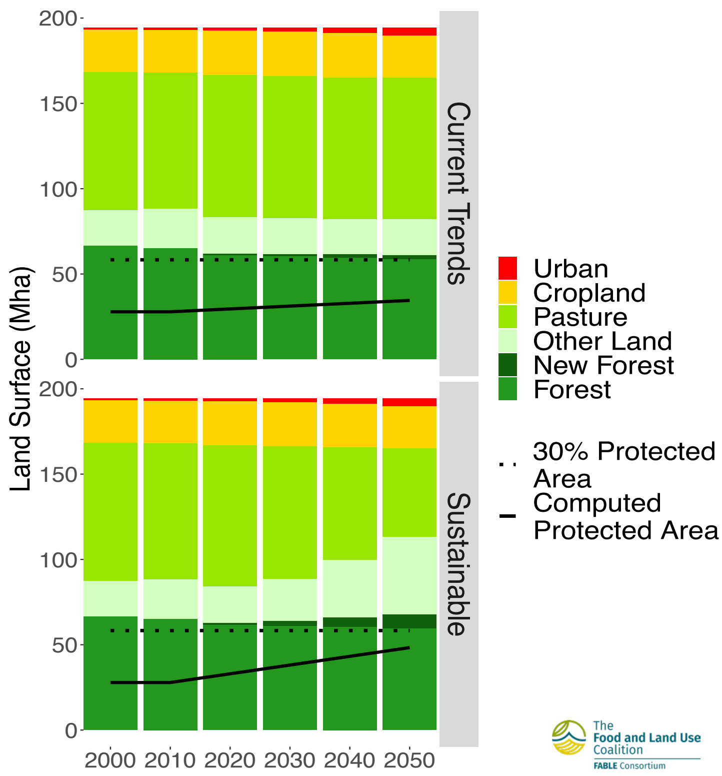
Pathways and Results

Projected land use in the Current Trends Pathway is based on several assumptions, including constraints on the expansion of agricultural land beyond its current area by 2015, 2.3 Mha reforested by 2050, and protected areas increase from 14 % of total land in 2010 to 18% in 2050 (see Annex 2).

By 2030, we estimate that the main changes in land cover in the Current Trends Pathway will result from an increase in pasture and cropland area and a decrease in forest area. This trend evolves over the period 2030-2050: forest and new forest area increases, pasture and cropland decreases (Figure 1). Initial pasture expansion is mainly driven by the increase in internal demand for beef due to its increasing role in the dietary mix, while livestock productivity per head and ruminant density per hectare of pasture remains stable over the period 2010-2050. Between 2030-2050, the decrease in cropland and pasture area is explained by the constraints in the expansion of agricultural land and the slow but steady increase of livestock productivity, increase in milk and beef imports, as well as a small rise in the population. This results in a stabilization of land where natural processes predominate at 27% by 2030, which remains the same by 2050 compared to 2010.

In the Sustainable Pathway, assumptions on agricultural land expansion, reforestation, and protected areas have been changed to reflect public policies aiming to improve crop productivity instead of increasing agricultural area, changes in livestock production systems to include silvo-pastoral systems with higher livestock productivity and as

Figure 1 | Evolution of area by land cover type and protected areas under each pathway

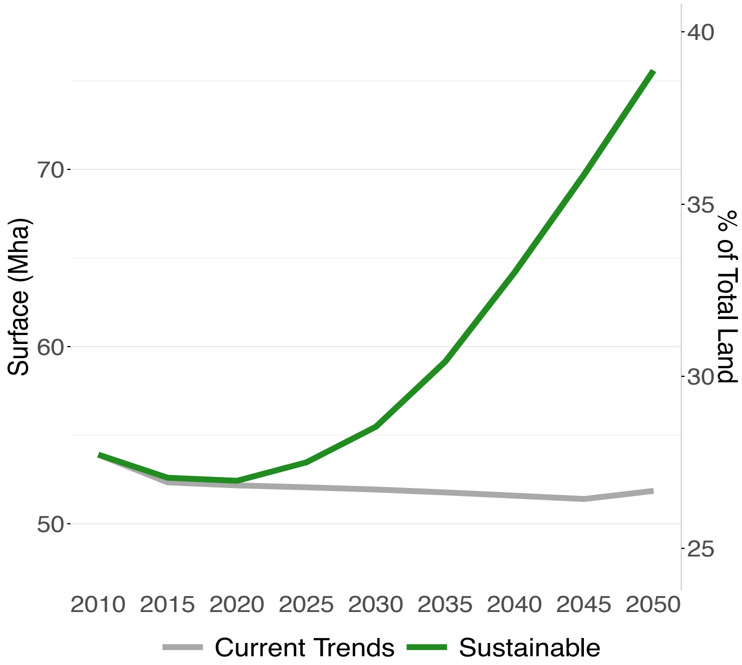


Source. Authors' computation based on FAOSTAT (FAO, 2020) for the area by land cover type for 2000, and the World Database on Protected Areas (UNEP-WCMC & IUCN, 2020) for protected areas for years 2000, 2005 and 2010.

well as international commitments for reforestation (Guevara Sanginés, Lara Pulido, Torres Rojo, & Betancourt Lopez, 2020; CIMMYT & SADER, 2018; SIAP, 2020). The main assumptions include constraints on the expansion of agricultural land beyond its 2016 area, 8.4 Mha reforested by 2050, and protected areas increase from 14 % of total land in 2010 to 30 % in 2050 (see Annex 2).

Compared to the Current Trends Pathway, we observe the following changes regarding the evolution of land cover in Mexico in the Sustainable Pathway: (i) a slight reduction in deforestation, (ii) the recovery of natural land in the form of other lands (all other types of vegetation in Mexico that are not forest types), (iii) a reduction in pasture, and (iv) an increase of reforested land. In addition to the changes in assumptions regarding land-use planning, these changes compared to the Current Trends Pathway are explained by a change in diets in which the consumption of fruit, vegetables, and pulses increases combined with a reduction in cereals and an implementation of strategies to increase crop and livestock productivity. This leads to an increase in the area where natural processes predominate: the area stops declining by 2025 and increases to 40% between 2010 and 2050 (Figure 2).

Figure 2 | Evolution of the area where natural processes predominate

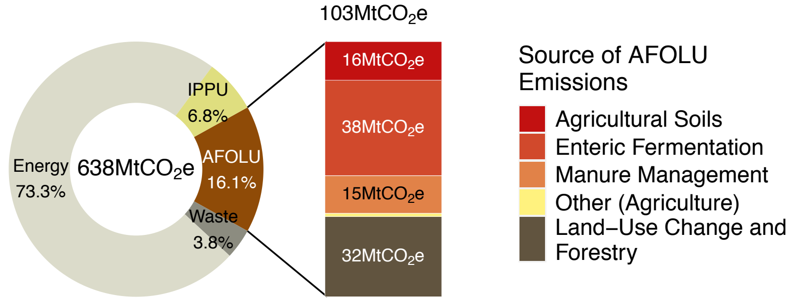


GHG emissions from AFOLU

Current State

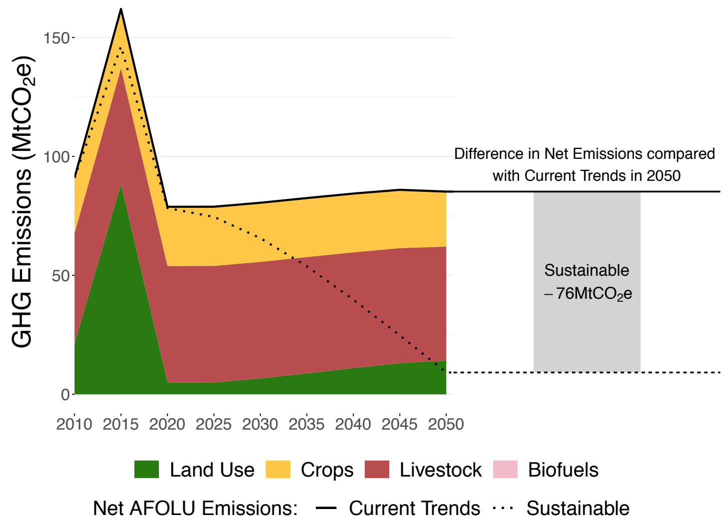
GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) accounted for 11.6% of total emissions in 2013 (Figure 3). Enteric fermentation and manure management are the main sources of AFOLU emissions, followed by agricultural soils and field burning of agricultural residues. This can be explained by an increase in beef consumption over the last 10 years due to dietary changes (Ibarrola-Rivas & Granados-Ramírez, 2017; Rivera, Barquera, González-Cossío, Olaiz, & Sepúlveda, 2004; Tello, Garcillán, & Ezcurra, 2020), consequently increasing the amount of cattle responsible for enteric fermentation, producing methane. Methane production is a serious problem linked to inefficiencies in bovine diets associated with traditional livestock production systems in temperate and tropical regions (Morante López et al., 2016). Additional important factors are the slash-and-burn cultivation practices used in the southeastern region of the country, the burning of grassland to induce revegetation and the increase in dry matter production for livestock breeding, and of course, the traditional practice of burning rather than harvesting residues (SEMARNAT, 2010). In the other extreme, high intensity agricultural practices involve the application of large quantities of fertilizers and pesticides for prolonged periods of

Figure 3 | Historical share of GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) to total AFOLU emissions and removals by source in 2013



Note. IPPU = Industrial Processes and Product Use
Source. Adapted from GHG National Inventory (UNFCCC, 2020)

Figure 4 | Projected AFOLU emissions and removals between 2010 and 2050 by main sources and sinks for the Current Trends Pathway



time, which are often applied incorrectly thus producing important volumes of GHG (Flores Lopez et al., 2012).

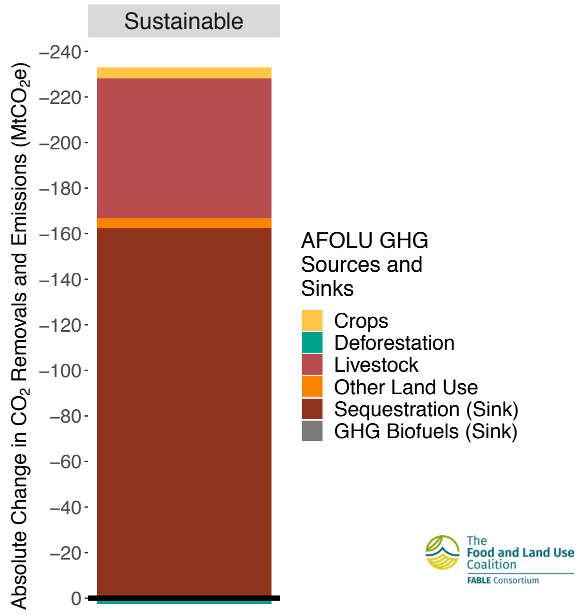
Pathways and Results

Under the Current Trends Pathway, annual GHG emissions from AFOLU increase to 81 Mt CO2e/yr in 2030, before reaching 86 Mt CO_2e/yr in 2045 and dropping to 85.2 Mt CO_2e/yr in 2050 (Figure 4). In 2050, livestock production is the largest source of emissions (48 Mt CO_2e/yr) while new forest act as a sink (-10.5 Mt CO_2e/yr). Over the period 2020-2050, the strongest relative increase in GHG emissions is computed for deforestation (164%) while a slight reduction is computed for crop production (-7.1%).

In comparison, the Sustainable Pathway leads to a reduction in AFOLU GHG emissions by 89% by 2050 compared to the Current Trends Pathway (Figure 4). The potential emissions reductions under the Sustainable Pathway is dominated by a reduction in GHG emissions from land use change and livestock production (Figure 5). Change in diets, adoption of strategies to increase productivity in crops and livestock are the most important drivers of this reduction.

Compared to Mexico's commitments under UNFCCC (Table 1), our results show that AFOLU could contribute to as much as 23% of its total GHG emissions reduction objective by 2050. Such reductions could be enhanced through the implementation of policy measures nationwide that would increase agricultural productivity. This can be done by improving the genetic base and updating agricultural practices for the production of corn and other grains. The MASAGRO program led by CIMMYT has been shown to be efficient in reaching this goal, by introducing a strong capacity building program based on productivity gains and the adoption of genetically improved seeds and cultural practices adapted to each municipality (CIMMYT and SADER 2018). For cattle ranching systems, increases in productivity could be achieved through the adoption of silvopastoral practices, which improve the menu of feeding components of traditional cattle diets, increasing weight gains and the herd carrying capacity per unit of area (Alejandro Guevara Sanginés et al. 2020).

Figure 5 | Cumulated GHG emissions reduction computed over 2020-2050 by AFOLU GHG emissions and sequestration source compared to the Current Trends Pathway



Furthermore, carbon sequestration can be enhanced by implementing programs that promote vegetation restoration and reforestation programs linked to agro-silvicultural practices such as the "Sembrando Vida Program" (DOF - Diario Oficial de la Federación 2020), the National Restoration program and a multitude of private and civil society initiatives (e.g. Reforestamos Mexico, Reforestación Extrema, among others) which add up to the reforestation commitments of the country (DC 2014). In addition, initiatives aimed to reduce pressure on land use change such as: a) the restoration of traditional systems of cattle ranching through the introduction of silvopastoral systems, b) the introduction of high productivity agrosilvicultural systems with the use of high value crops in the agriculture-forest interface, and c) support to different demand-driven mechanisms to increase demand for products with a deforestation-free supply chain, contributing to the recovery of low agricultural productivity areas into natural vegetation lands. These measures could be particularly important when considering options for NDC enhancement.

Food Security

Current State

The "Triple Burden" of Malnutrition

Undernutrition

10% of children under 5 years were stunted and 1.9% were wasted in 2016 (Cuevas-Nasu et al., 2018).

The share of stunted children has decreased from 13.6% in 2012; while the share of wasted children has increased from 1.6% in 2012 (Cuevas-Nasu et al. 2018).

Micronutrient Deficiency

12.6% of women, 26.9% of preschoolers and 12.5% of school children suffer from anemia in 2016, which can lead to maternal death (Cruz-Góngora, Martínez-Tapia, Cuevas-Nasu, Flores-Aldana, & Shamah-Levy, 2017).

54.8% of women had a dietary intake less than the requirement of vitamin A in 2012 (Pedroza-Tobías et al., 2016). By biochemical indicator, 15.7% of preschool children (12 to 59 months) were deficient in vitamin A in 2012 (Villalpando, De la Cruz, Shamah-Levy, Rebollar, & Contreras-Manzano, 2015), which can notably lead to blindness and child mortality.

Overweight/ Obesity

In 2016, 41.7% of men and 37% of women were overweight; 32.4% of men and 37.5% of women were obese (Instituto Nacional de Salud Pública & Secretaría de Salud, 2020).

In preschool children, 5.8% of girls and 6.5% of boys were overweight or obese in 2016. In scholar children (5-11 years old) the prevalence of overweight and obesity in girls was 20.6% and 12.2% respectively, while in boys, it was 15.4% and 18.3% in 2016 (Hernández-Cordero et al., 2017).

For adolescents, the prevalence of overweight was 26.4% in girls and 18.5% in boys; and obesity 12.8% in girls and 15% in boys in 2016 (Hernández-Cordero et al. 2017). These shares were similar between the age groups, except in female adolescents and adults, whose prevalence increased compared to 2012 (Instituto Nacional de Salud Pública & Secretaría de Salud, 2020; Shamah-Levy et al., 2018).

Disease Burden due to Dietary Risks

189 to <249 deaths per year are attributable to dietary risks.

35 deaths and 1,605 DALYS due to type 2 diabetes per 100,000 population (Afshin et al., 2019).

In 2012, 9.4% (with previous diagnosis) of the population suffers from diabetes (Rojas-Martínez et al., 2018).

Table 3 | Daily average fats, proteins and kilocalories intake under the Current Trends and Sustainable Pathways in 2030 and 2050

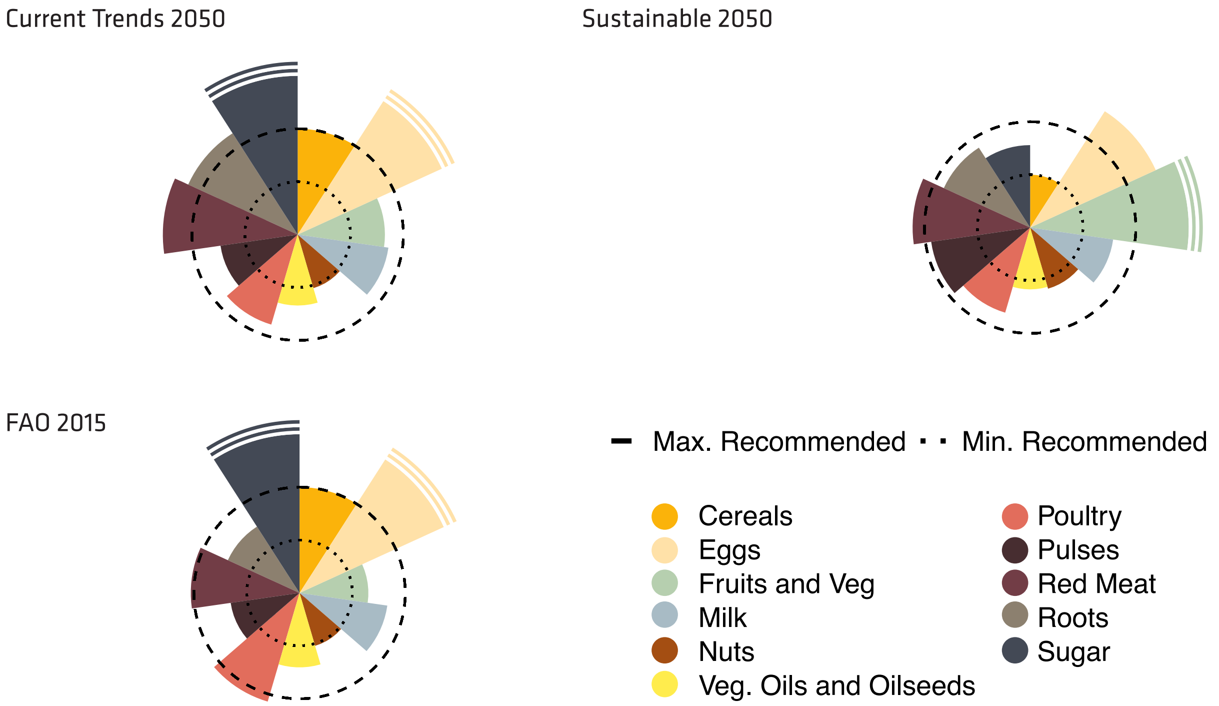
	2010	2030		2050	
	Historical Diet (FAO)	Current Trends	Sustainable	Current Trends	Sustainable
Kilocalories (MDER)	2,760 (2,052)	2,607 (2,086)	2,613 (2,086)	2,520 (2,090)	2,378 (2,090)
Fats (g) (recommended range	85 (61-92)	86 (58-87)	83 (58-87)	93 (56-84)	78 (53-79)
Proteins (g) (recommended range	81 (69-241)	78 (65-228)	83 (65-228)	80 (63-221)	89 (59-208)

Notes. Minimum Dietary Energy Requirement (MDER) is computed as a weighted average of energy requirement per sex, age class, and activity level (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015) and the population projections by sex and age class (UN DESA, 2017) following the FAO methodology (Wanner et al., 2014). For fats, the dietary reference intake is 20% to 30% of kilocalories consumption. For proteins, the dietary reference intake is 10% to 35% of kilocalories consumption. The recommended range in grams has been computed using 9 kcal/g of fats and 4kcal/g of proteins.

Pathways and Results

Under the Current Trends Pathway, compared to the average Minimum Dietary Energy Requirement (MDER) at the national level, our computed average calorie intake is 25% higher in 2030 and 21% higher in 2050 (Table 3). The current average intake is mostly satisfied by eggs, red meat, roots and sugars, with cereals representing 60% of the total calorie intake. We assume that the consumption of roots, dairy and red meat, will increase by 173%, 25%, and 42%, respectively, between 2020 and 2050. The consumption of nuts, fruits and vegetables, and eggs will also increase while the consumption of cereals, poultry, and sugar will slightly decrease. Compared to the EAT-LANCET recommendations, cereals, roots, sugar, red meat and eggs are over-consumed while nuts and pulses are close to the minimum recommended levels (Figure 6). Moreover, fat and protein intake does not follow the same trend, while fat intake is on the upper boundary of the DRI, protein intake falls on the lower boundary in 2030. In 2050, fat intake follows the same trend and exceeds the DRI while protein intake remains on the lower boundary of the recommended dietary intake. This can be explained by an increase in consumption of oil and fat, milk products, and eggs (Figure 6).

Figure 6 | Comparison of the computed daily average kilocalories intake per capita per food category across pathways in 2050 with the EAT-Lancet recommendations



Notes. These figures are computed using the relative distances to the minimum and maximum recommended levels (i.e. the rings) i.e. different kilocalorie consumption levels correspond to each circle depending on the food group. The EAT-Lancet Commission does not provide minimum and maximum recommended values for cereals: when the kcal intake is smaller than the average recommendation it is displayed on the minimum ring and if it is higher it is displayed on the maximum ring. The discontinuous lines that appear at the outer edge of sugar, eggs, and fruits and vegetables indicate that the average kilocalorie consumption of these food categories is significantly higher than the maximum recommended.

Under the Sustainable Pathway, we assume that diets will transition towards a healthier consumption of fats and oils, with a lower reliance on cereals, and with a substantial increase in the intake of fruits and vegetables, pulses, and nuts. The ratio of the computed average intake over the MDER increases to 25% in 2030 and 14% in 2050. Compared to the EAT-LANCET recommendations, the consumption of eggs and red meat remains outside of the recommended range with the consumption of sugar and roots within the recommended range in 2050 (Figure 6). Moreover, the fat intake per capita is still on the upper boundary of the dietary reference intake (DRI) but the protein intake increases in 2030, showing some improvement compared to the Current Trends Pathway.

To promote a necessary shift in diets it is necessary to implement measures that encourage consumers to make healthier food choices. Placing nutrition labels in front of the food packages (Jáuregui et al. 2020), including a purchase tax to reduce sales of sugar-sweetened beverages and increase consumption of untaxed beverages (Colchero, Molina, and Guerrero-López 2017) are some of the general strategies that have been proposed. However, the most important policies need to address the obesity epidemic for school-age children, such as the development of dedicated school curricula where one of the components is the access and availability of food and beverages that facilitate a healthy diet. This policy already was created in 2010 but it has not been fully implemented. It includes the development of general guidelines for the sale and distribution of food and beverages in elementary schools. These guidelines have the objective of facilitating an adequate diet for children in schools and have a structured and unified regulation among states (Secretaría de Salud 2010; Secretaría de Salud and Secretaría de Educación 2014).

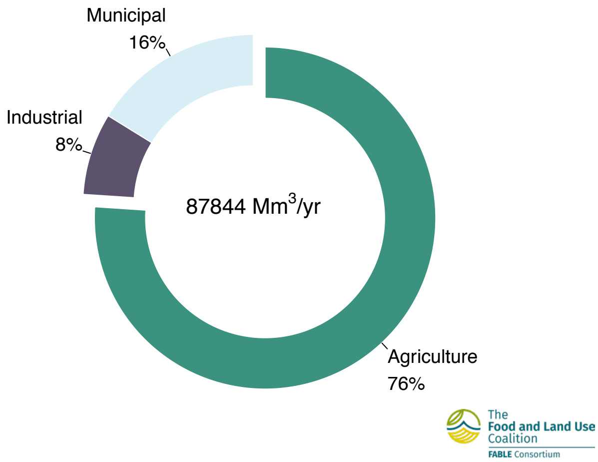
Water

Current State

Mexico is characterized by its diverse climatic conditions, high climate and rainfall variability. The climate ranges from dry regions with mean temperatures above 32°C and precipitation that varies between 60 to 400mm per year, to tropical regions with mean temperatures above 20°C and 800 to 4500mm of precipitation. Between these two extremes are temperate regions with mean temperatures below 10°C, 700 to 1,000mm of precipitation, and that are 1,600 meters above sea level. Precipitation mostly occurs over the period June – October with a limited region of winter rain in the northwestern part of the country.

The agricultural sector represented 76% of total water withdrawals in 2017 (Figure 7; FAO 2020). Moreover in 2016, 32% of agricultural land was equipped for irrigation, representing 33% of estimated-irrigation potential. The three most important irrigated crops, maize, wheat, and sorghum, account for 28%, 12%, and 12% of total harvested irrigated area. Mexico exported 3.1% of corn, 0.81% of wheat, and 0.02% of sorghum in 2016.

Figure 7 | Water withdrawals by sector in 2017

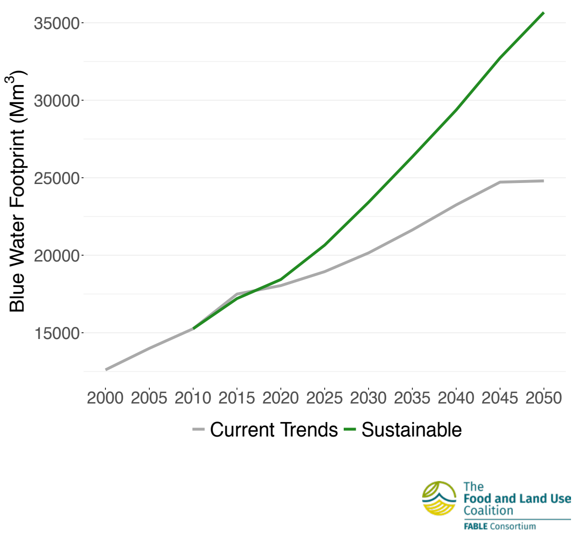


Source. Adapted from AQUASTAT Database (FAO, 2017)

Pathways and Results

Under the Current Trends Pathway, annual blue water use increases between 2000-2015 (12,605 Mm^3/yr and 17,494 Mm^3/yr), before reaching 20,149 Mm^3/yr and 24,796 Mm^3/yr in 2030 and 2050, respectively (Figure 8), with wheat, rice, and corn accounting for 41%, 32%, and 12% of computed blue water use for agriculture by 2050[3]. In contrast, under the Sustainable Pathway, the blue water footprint in agriculture reaches 23,415 Mm^3/yr in 2030 and 35,669 Mm^3/yr in 2050. This increase in demand for blue water is explained mainly by an increase in production of fruits and vegetables due to dietary shifts and increased exports (see Annex 2) leading to a 1.8% increase in water use for irrigation by 2050 despite increases in imports for milk and beef that would reduce water use dedicated to feed production.

Figure 8 | Evolution of blue water footprint in the Current Trends and Sustainable Pathways



3 We compute the blue water footprint as the average blue fraction per tonne of product times the total production of this product. The blue water fraction per tonne comes from Mekonnen and Hoekstra (2010a, 2010b, 2011). In this study, it can only change over time because of climate change. Constraints on water availability are not taken into account.

Resilience of the Food and Land-Use System

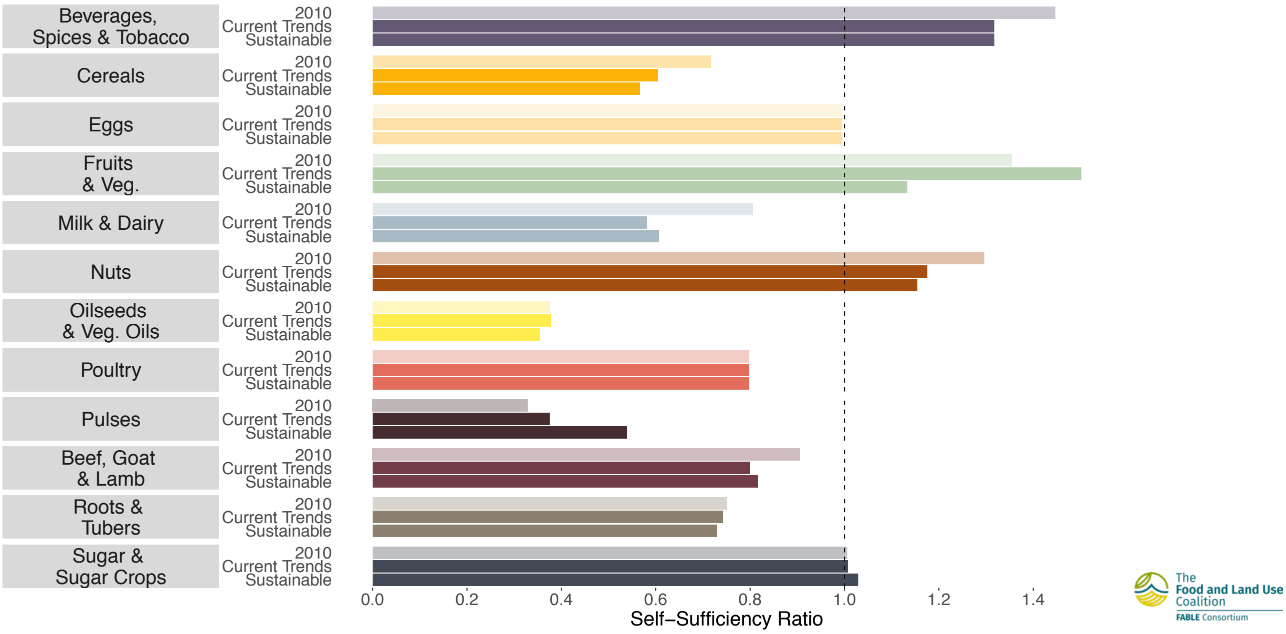
The COVID-19 crisis exposes the fragility of food and land-use systems by bringing to the fore vulnerabilities in international supply chains and national production systems. Here we examine two indicators to gauge Mexico's resilience to agricultural-trade and supply disruptions across pathways: the rate of self-sufficiency and diversity of production and trade. Together they highlight the gaps between national production and demand and the degree to which we rely on a narrow range of goods for our crop production system and trade.

Self-Sufficiency

Currently, the self-sufficiency for some basic products, such as pulses and industrial crops, is at high risk. These crops began losing importance with the introduction of programs to promote the cropping of corn and other basic products (Riedemann 2007). However, the current production of cereals does not guarantee self-sufficiency for products such as wheat, yellow corn, and sorghum, the demand for which has increased markedly due to demand in balanced food products in the poultry, pig, and cattle meat industries (Martínez Damián, Téllez Delgado, and Mora Flores 2018; Nuñez Melgoza and Sempere Campello 2016). Dairy products and most meats are also not trending towards self-sufficiency. High costs of labor, poor technology, and inefficient diets for the production of milk generate an inefficient milk sector that is unable to compete at the international level (Rebollar et al. 2016). Meanwhile, the poultry and pig industries are constrained by the domestic market structure of inputs, despite showing high growth (Martinez-Gomez 2013).

Under the Current Trends Pathway, we project that Mexico would be self-sufficient in eggs, sugar and sugar crops, nuts, fruits and vegetables, and spices, beverages and tobacco in 2050, with self-sufficiency by product group remaining stable for the majority of products from 2010 – 2050 (Figure 9). The product groups on which the country depends the most on imports are milk and dairy, pulses, oil and vegetable seeds, and cereals, a dependency that will remain stable until 2050. Under the Sustainable Pathway, Mexico's self-sufficiency does not change compared to the Current Trend Pathways, it is still self-sufficient in the same product groups as in 2010 and a trend that does not change by 2050. Imports of beef, milk, and corn in 2050 to reduce Mexico's environmental costs does not promote self-sufficiency for those important product groups (Martinez-Melendez and Bennett 2016).

Figure 9 | Self-sufficiency per product group in 2010 and 2050



Note. In this figure, self-sufficiency is expressed as the ratio of total internal production over total internal demand. A country is self-sufficient in a product when the ratio is equal to 1, a net exporter when higher than 1, and a net importer when lower than 1.

Diversity

The Herfindahl-Hirschman Index (HHI) measures the degree of market competition using the number of firms and the market shares of each firm in a given market. We apply this index to measure the diversity/concentration of:

- **Cultivated area:** where concentration refers to cultivated area that is dominated by a few crops covering large shares of the total cultivated area, and diversity refers to cultivated area that is characterized by many crops with equivalent shares of the total cultivated area.
- **Exports and imports:** where concentration refers to a situation in which a few commodities represent a large share of total exported and imported quantities, and diversity refers to a situation in which many commodities account for significant shares of total exported and imported quantities.

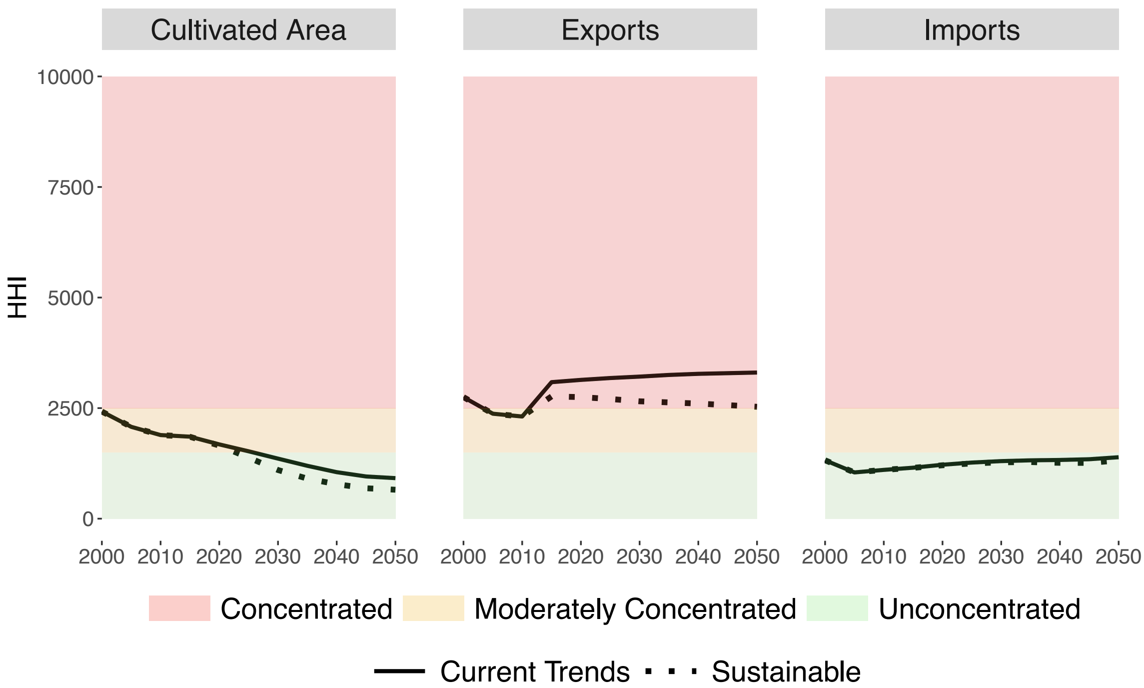
We use the same thresholds as defined by the U.S. Department of Justice and Federal Trade Commission (2010, section 5.3): diverse under 1,500, moderate concentration between 1,500 and 2,500, and high concentration above 2,500.

Despite a trend of increasing diversification of crops driven by the commercial openness with the US and Canadian markets, the primary sector is still concentrated in very few crops. Cereals, mainly corn, cover more than 70% of the cropping area in the country. However, there is clear scope for greater diversification, which will improve the use of productive land and irrigation water, increase the returns to and wellbeing of producers, and increase the availability of more products.

Current exports are concentrated in very few products (avocado, tequila, fruits, berries, and vegetables) and this concentration remains even under the Sustainable Pathway. This concentration of products is related to market opportunities, investment and capacities needed to maintain supply chain with high standards. Thus, such a trend will remain as long as the programs aimed at promoting new markets do not take off.

Under the Current Trends Pathway, we project high concentration of crop exports, relatively low concentration of imports and a trend towards decreased concentration in crops planted in 2050, trends which are consistent over the period 2010 – 2050. This indicates high levels of diversity across the national production system and imports, but low diversity among exports. Under the Sustainable Pathway, the evolution of the diversification is similar to the Current Trends Pathway with a lower concentration of exports (albeit still high) and even lower concentration of crops planted in 2050, indicating high levels of diversity across the national production system (Figure 10).

Figure 10 | Evolution of the diversification of the cropland area, crop imports and crop exports of the country using the Herfindahl-Hirschman Index (HHI)



Discussion and Recommendations

Mexico needs to promote highly productive and sustainable food systems that will increase its self-sufficiency in key products groups (animal protein, pulses, and cereals). Mexico also needs to enact policies to ensure that pressure for land conversion is reduced and that the Mexican population has access to the food it needs. The FABLE project provides an integrated pathway for sustainable land use that can inform Mexico's long-term strategy and the land-use component of the country's NDC. Results suggest that Mexico can adopt a feasible land-use pathway that ensures adequate nutrition for the population, sets a limit to further agricultural expansion, and expands natural habitats. The results also suggest that, over the coming decades, food security is possible without sacrificing Mexico's natural capital.

The results highlight that the key national trade-offs in food and land-use systems involve the promotion of national self-sufficiency through a reduction in imports, at the expense of pastureland. Food production in Mexico has enormous potential for sustainability. It has policies that, if correctly and fully applied, would promote production systems that are highly productive and are also environmentally sustainable in terms of improved water use and GHG reduction. Nevertheless, a large proportion of food would have to be imported. On a 2050 horizon, Mexico is unlikely to be self-sufficient in important food groups (meat from cattle and poultry, milk and dairy, cereals and pulses). Even if the country transitions towards a healthier diet, much of the required protein intake will need to be imported.

The results also highlight the important role that diet plays in reducing land-use change and GHG emissions. A change towards a healthier diet implies a reduction in the intake of cereals and sugar but also an increase in fruits, vegetables, and nuts, and a healthy consumption of animal protein, which includes a higher intake of red meat and dairy products (Villalpando et al., 2015). These changes would affect what is produced in Mexico and what needs to be imported. Without importing beef, milk, and corn for animal feed, the reduction in pasture would not be possible, even with better practices and more productive livestock systems.

An important limitation of this analysis that can be improved in future work relates to the scenario assumptions. In 2019, the Mexican government published its National Development Plan for 2019-2024, with the goal of improving the well-being of Mexicans through sustainable development. While the 2020 FABLE Report was being prepared, we did not have complete information on the programs and operating rules that key federal agencies were considering (e.g., Sustainable Forest Development programs from CONAFOR), or updates on Mexico's international commitments (e.g., INECC will submit Mexico's second NDC in late 2020). Moreover, the federal government has recently created an intersectoral group called "Health, Agriculture, Environment and Competitiveness" (GISAMAC in Spanish). GISAMAC aims to support new forms of agricultural and forestry production to reduce the negative effects on human health and wildlife (SEMARNAT 2020). Under the coordination of the Ministry of Environment, and in collaboration with 18 working groups from more than 10 government agencies and research institutes, GISAMAC focuses on harmonization of public policies to promote sufficient and sustainable production of healthy foods, prioritizing production from family farm producers and medium-sized producers as well as the protection and restoration of ecosystem services.

During the coming months, the Mexican FABLE team will continue to reach out to key Mexican government stakeholders to promote integrated modeling frameworks. Together with other members of the Mexican academic community, this integrated modeling can help ensure policy coherence between the land sector of the country's NDC, the NBSAP, and strategic plans for agricultural self-sufficiency, each authored by different government agencies. Importantly, the results of this exercise highlight the transformative impact that diets have on land-use systems. As such, diet transformation should be included in all climate mitigation plans. In addition, the FABLE team plans to extend the FABLE Calculator with new scenarios to model policies that Mexico might adopt in the coming years. Finally, the team has begun engaging state-level governments to inform their long-term planning to meet the SDGs, and plans to adapt the FABLE Calculator so that Mexican states can model their own sustainable land use pathways at the state level.

The COVID-19 crisis has generated new challenges for Mexico's food systems. In rural areas where health care systems are scarce or nonexistent, local populations have implemented strict controls on accessing their localities as a means of preventing the spread of COVID-19 (Jimenez-Ferrer 2020). These controls have disrupted supply chains for basic foods and commodities, resulting in an increase in prices of crucial goods (e.g., meat, eggs, sugar, medicines, gasoline, etc.), adversely affecting already fragile local economies.

Moreover, reduced mobility to larger cities and the return of the migrant population from the US may lead to an increase in the extent of agricultural lands (e.g. for the production of beans and corn) or forest products. At the same time, the shortage in beef supply in the US is resulting in an increase in Mexico's beef exports to the US (Alire and Huffstutter 2020), potentially increasing the pressure for land conversion to cultivated grasslands but taking advantage of the Mexico's small scale operations where the disease is easier to keep at bay.

Finally, the COVID-19 crisis is decreasing demand for forests products and services. Out of the almost 55 million hectares of tropical and temperate forests in Mexico, only 5.5 million hectares are managed with approved plans for timber extraction. With the current sanitary crisis, the demand for products and services in Mexico's forest sector is drastically decreasing (50-70% reduction) (Mongabay Latam, 2020). National associations of community forestry already estimate a 60% loss in the 160,000 jobs generated by the industry, putting at risk more than three decades of collective work among local communities, foresters, and civil society organizations that consolidated sound management practices and forest conservation, while potentially increasing timber imports and opening the way for the expansion of the agricultural frontier (Mongabay Latam, 2020).

Annex 1. List of changes made to the model to adapt it to the national context

- Crop productivity for four most important crops (maize, beans, wheat, and sorghum) were adapted to reflect Mexican trends under two pathways: Current Trends where the productivity followed the same increase trend as 2006 – 2016 and in the Sustainable Pathway we followed the MASAGRO (CIMMYT & SADER, 2018) program's expected productivity in maize, beans, wheats and sorghum (SAGARPA, 2017).
- Livestock productivity, two scenarios were generated: for the Current Trends Pathway, where livestock productivity followed the same trend of improvement as the period 2000 – 2010 and the Sustainable Pathway, where high-productivity livestock systems based on modern silvopastoral systems were calculated for cattle (Guevara Sanginés et al., 2020; SIAP, 2020)
- Reforestation, scenario for the Current Trends Pathway contemplates the reforestation that occurred from 2010 to 2020 and the intention of reforestation of two programs "Sembrando Vida" and "Programa de restauración forestal". For the Sustainable Pathway, the reforestation occurred from 2010 to 2020 and the BonnChallenge (2019; DOF, 2020; SEMARNAT, 2020)
- Diets, two scenarios were generated, a current diet that mimics the average diet in Mexico and a healthy diet that follows national and international recommendations for sustainability and health (Barquera, Campos, & Rivera, 2013; Behrens et al., 2017; Cruz-Góngora et al., 2017; Fernández-Gaxiola et al., 2015; Willett et al., 2019)
- Protected areas, for the Current Trends Pathway a goal of 17% of total terrestrial area was included, for the Sustainable Pathway the goal of 30% was set.

Annex 2. Underlying assumptions and justification for each pathway

POPULATION Population projection (million inhabitants)	
Current Trends Pathway	**Sustainable Pathway**
The population is expected to reach 146 million by 2050 (name of scenario selected). (CONAPO 2018) (UN_Low scenario selected)	Same as Current Trends

LAND Constraints on agricultural expansion	
Current Trends Pathway	**Sustainable pathway**
We assume no expansion of agricultural land beyond 2016 agricultural area levels. This is a national policy since 2017 and it is being included as is by the new federal Government. (SAGARPA 2017) *(For Scenario: No productive land expansion beyond 2010 value)*	Same as Current Trends
LAND Afforestation or reforestation target (Mha)	
We assume total afforested/reforested area to reach 2.2 Mha by 2020/2030/2050. (DOF - Diario Oficial de la Federación 2020; SEMARNAT 2020) The reforestation efforts from 2010 to 2020 were included, a 30 % of the area intended for the Federal program Sembrando Vida (2019-2024) and finally 30 % of the area for the program "Restauración Forestal". (ReforestationMexBAU scenario selected)	We assume total afforested/reforested area to reach 8.4 Mha by 2050. (DC 2014; SEMARNAT 2020) *Mexico has signed the BonnChallenge which we used to add to the efforts of reforestation from 2010 to 2018.* (BonnChallenge scenario selected)

BIODIVERSITY Protected areas (1000 ha or % of total land)	
Current Trends Pathway	**Sustainable Pathway**
Protected areas increase by 2050 they represent 17.8% of total land. Mexico has signed the Convention on Biological Diversity and agree to include in Protected areas 17% of its territory. (CONABIO 2016)	Protected areas increase: by 2050 they represent 25% of total land. Use of several conservation instruments to reach 30% of total land area under protection (CONABIO 2016)

Mexico

PRODUCTION Crop productivity for the key crops in the country (in t/ha)

Current Trends Pathway	Sustainable Pathway
By 2050, crop productivity reaches: • 6.2 tons per ha for corn • 1.5 tons per ha for beans • 5.9 tons per ha for wheat Crop productivity for 4 most important crops (maize, beans, wheat and sorghum) were adapted to reflect Mexican of crop productivity following the same increase trend than 2006 – 2016. (SIAP 2017)	By 2050, crop productivity reaches: • 10 tons per ha for corn • 2.2 tons per ha for beans • 6.3 tons per ha for wheat Based on (Masagro, Siap). Crop productivity increase if the MASAGRO program was implemented for the principal crop (Maize). For the rest other two crops we used the projections generated by the "Planeación Nacional Agrícola" for a sustainable increment on crop productivity (CIMMYT and SADER 2018; SAGARPA 2017).

PRODUCTION Livestock productivity for the key livestock products in the country (in kg/head of animal unit)

Current Trends Pathway	Sustainable Pathway
By 2050, livestock productivity reaches: • 80.7 kg per head for cattle • 86 kg per head for pork Following the trend of increase productivity from 2000 – 2010. (SIAP 2020)	By 2050, livestock productivity reaches: • 105.5 kg per head for cattle • 126.4 kg per head for pork Mexico has programs to promote silvopastoral systems for cattle. (Alejandro Guevara Sanginés et al. 2020)

PRODUCTION Pasture stocking rate (in number of animal heads or animal units/ha pasture)

Current Trends Pathway	Sustainable Pathway
By 2050, the average ruminant livestock stocking density is 12 animals/ha per ha. National pasture stocking rate without implementing any program to increase productivity in a sustainable way. (COTECOCA - SEMARNAT 2014)	By 2050, the average ruminant livestock stocking density is 24 animals/ha per ha. Silvopastoral systems have the capacity to double the density of animals per hectare. (Alejandro Guevara Sanginés et al. 2020; SEMARNAT 2010)

PRODUCTION Post-harvest losses

Current Trends Pathway	Sustainable Pathway
By 2050, the share of production and imports lost during storage and transportation is 10%. However, Mexico does not have data on food loss at national or regional level. (Gustavsson, Cederberg, and Sonesson 2011).	By 2050, the share of production and imports lost during storage and transportation is 5%. Mexico does not have data on food loss at national or regional level. (Gustavsson et al. 2011)

TRADE Share of consumption which is imported for key imported products (%)

Current Trends Pathway	Sustainable Pathway
By 2050, the share of total consumption which is imported is: • 54% for corn for animal feed • 40% by 2050 for milk • 18% by 2050 for beef Products with a high agricultural and water footprint were selected to be imported as other countries are more environmentally efficient in their production.	Same as Current Trends

TRADE Evolution of exports for key exported products (1000 tons)

Current Trends Pathway	Sustainable Pathway
By 2050, the volume of exports is: • 12,600 mil tons by 2050 for veggies • 5,300 mil tons by 2050 for tomatoes • 3,600 mil tons by 2050 for fruits The selected crops are the same that Mexico mainly export taking advantage of its environment conditions that allows it to grow these crops most of the year (SAGARPA 2017).	By 2050, the volume of exports is: • 7,200 tons by 2050 for veggies • 3,600 mil tons by 2050 for fruits • 3,200 mil tons by 2050 for tomatoes According to Mexico's agricultural planning, the country has the capacity to reconvert part of its crops land towards high value crop exports taking advantage of its environmental conditions. (Martinez-Melendez and Bennett 2016; SAGARPA 2017).

FOOD Average dietary composition (daily kcal per commodity group)

Current Trends Pathway	Sustainable Pathway
By 2030, the average daily calorie consumption per capita is 2683 kcal and is: • 1012 kcal for cereals • 323 kcal for Oils and fats • 352 kcal for sugar Current diet that mimics the average diet in Mexico.	By 2030, the average daily calorie consumption per capita is 2633 kcal and is: • 992 kcal for cereals • 276 kcal for sugar • 262 kcal for fruits and vegetables Healthy diet that follows national and international recommendations for sustainability.

FOOD Share of food consumption which is wasted at household level (%).

Current Trends Pathway	Sustainable Pathway
Mexico does not have data. We used FAO data for Latin American Countries. By 2030, the share of final household consumption which is wasted at the household level is: • Cereals 9% • Fish 3% • Fruit and Veg 8% • Milk 4% • Fats and oils 2% • Pulses 2% • Red meat 5% • Roots 4% • Poultry 6% (Gustavsson et al. 2011)	Same as Current Trends

BIOFUELS Targets on biofuel and/or other bioenergy use

Current Trends Pathway	Sustainable Pathway
Mexico does not participate on biofuels production.	Mexico does not participate on biofuels production.

CLIMATE CHANGE Crop model and climate change scenario

Current Trends Pathway	Sustainable Pathway
By 2100, global GHG concentration leads to a radiative forcing level of 6 W/m^2 (RCP 6.0). Impacts of climate change on crop yields are computed by the crop model GEPIC using climate projections from the climate model Ha HadGEM2-E without CO_2 fertilization effect	By 2100, global GHG concentration leads to a radiative forcing level of 2.6 W/m^2 (RCP 2.6). Impacts of climate change on crop yields are computed by the crop model GEPIC using climate projections from the climate model Ha HadGEM2-E without CO_2 fertilization effect.

Annex 3. Correspondence between original ESA CCI land cover classes and aggregated land cover classes displayed on Map 1

FABLE classes	ESA classes (codes)
Cropland	Cropland (10,11,12,20), Mosaic cropland>50% - natural vegetation <50% (30), Mosaic cropland><50% - natural vegetation >50% (40)
Forest	Broadleaved tree cover (50,60,61,62), Needleleaved tree cover (70,71,72,80,82,82), Mosaic trees and shrub >50% - herbaceous <50% (100), Tree cover flooded water (160,170)
Grassland	Mosaic herbaceous >50% - trees and shrubs <50% (110), Grassland (130)
Other land	Shrubland (120,121,122), Lichens and mosses (140), Sparse vegetation (150,151,152,153), Shrub or herbaceous flooded (180)
Bare areas	Bare areas (200,201,202)
Snow and ice	Snow and ice (220)
Urban	Urban (190)
Water	Water (210)

Annex 4. Overview of biodiversity indicators for the current state at the ecoregion level[4]

	Ecoregion	Area (1,000 ha)	Protected Area (%)	Share of Land where Natural Processes Predominate (%)	Share of Land where Natural Processes Predominate that is Protected (%)	Share of Land where Natural Processes Predominate that is Unprotected (%)	Cropland (1,000 ha)	Share of Cropland with at > 10% natural vegetation within 1km^2(%)
426	Baja California desert	7733.195	61	64.5	71.8	28.2	173.87	53.4
521	Bajío dry forests	3757.509	7.5	5.1	2.4	97.6	1963.573	31.6
522	Balsas dry forests	6258.079	10.9	8.3	41.2	58.8	1451.669	45.7
564	Belizian pine savannas	0.006	0	0	0	0	0.006	100
422	California coastal sage and chaparral	1177.622	4.6	52.7	8.5	91.5	21.82	67.7
424	California montane chaparral and woodlands	400.951	16.9	79.2	21.4	78.6	0.322	100
527	Central American dry forests	324.717	14.5	7.7	28.5	71.5	214.245	37
451	Central American montane forests	0.174	90.2	66.1	78.3	21.7	0	0
553	Central American pine-oak forests	1601.563	16.1	36.6	14.4	85.6	31.913	93.5
427	Central Mexican matorral	5948.704	5.4	1.6	60.2	39.8	1963.556	41.4
528	Chiapas Depression dry forests	1315.68	2.8	13.4	7.5	92.5	132.72	78.8
452	Chiapas montane forests	559.097	4.4	43.5	9.3	90.7	5.926	99.7
428	Chihuahuan desert	30439.285	8.4	27.6	10.5	89.5	1581.504	43.1
453	Chimalapas montane forests	208.83	13.6	82.3	10.1	89.9	1.325	94
431	Gulf of California xeric scrub	2311.985	48.9	52.5	66.3	33.7	4.786	78.9
533	Islas Revillagigedo dry forests	13.81	100	70.7	100.7	0	0	0
534	Jalisco dry forests	2545.171	9	7.7	26	74	670.455	43.9
432	Meseta Central matorral	12554.552	5.3	10.9	8.6	91.4	1540.564	45.7
613	Mesoamerican Gulf-Caribbean mangroves	1543.517	63.6	44.1	84.3	15.7	206.024	52.9
614	Northern Mesoamerican Pacific mangroves	665.328	55	16.8	90.3	9.7	109.172	46.5

4 The share of land within protected areas and the share of land where natural processes predominate are percentages of the total ecoregion area (counting only the parts of the ecoregion that fall within national boundaries). The shares of land where natural processes predominate that is protected or unprotected are percentages of the total land where natural processes predominate within the ecoregion. The share of cropland with at least 10% natural vegetation is a percentage of total cropland area within the ecoregion

Mexico

	Ecoregion	Area (1,000 ha)	Protected Area (%)	Share of Land where Natural Processes Predominate (%)	Share of Land where Natural Processes Predominate that is Protected (%)	Share of Land where Natural Processes Predominate that is Unprotected (%)	Cropland (1,000 ha)	Share of Cropland with at > 10% natural vegetation within $1km^2$(%)
487	Oaxacan montane forests	761.754	2	80.1	2.5	97.5	17.129	88.2
489	Pantanos de Centla	1712.738	28.4	20.5	74.1	25.9	484.896	52
494	Petén-Veracruz moist forests	8434.754	11.3	25.1	29.9	70.1	3009.942	39.6
607	San Lucan xeric scrub	364.328	17.2	2.7	62.3	37.7	10.166	81.1
544	Sierra de la Laguna dry forests	397.285	23	5	87.9	12.1	3.351	94.9
556	Sierra de la Laguna pine-oak forests	106.598	86.8	60	94.9	5.1	1.591	100
501	Sierra de los Tuxtlas	386.727	39.3	39.6	97.4	2.6	161.262	58.1
502	Sierra Madre de Chiapas moist forests	543.602	33.4	55.3	49.5	50.5	41.275	65.2
557	Sierra Madre de Oaxaca pine-oak forests	1437.723	6.5	62.8	8.7	91.3	29.224	90.6
558	Sierra Madre del Sur pine-oak forests	6131.229	2.9	51.4	2.7	97.3	155.151	87.8
326	Sierra Madre Occidental pine-oak forests	21590.017	13.1	29.8	12.2	87.8	529.237	59.8
327	Sierra Madre Oriental pine-oak forests	6175.926	32.9	38.5	48	52	144.676	68
545	Sinaloan dry forests	7762.602	11.1	17.9	19.2	80.8	1589.752	33
435	Sonoran Desert	10621.743	13.5	36.6	27.8	72.2	561.571	43.1
324	Sonoran-Sinaloan subtropical dry forest	5074.817	5.1	6.9	2.3	97.7	980.109	21.6
617	Southern Mesoamerican Pacific mangroves	141.411	63.1	52.2	57.2	42.8	20.576	67.3
547	Southern Pacific dry forests	4180.064	4.2	31.1	8.1	91.9	944.039	66.5
436	Tamaulipan matorral	1630.757	6.2	3.7	43.7	56.3	341.593	46.6
437	Tamaulipan mezquital	7188.567	9.6	14.1	12.2	87.8	1021.987	62
610	Tehuacán Valley matorral	991.45	16.3	4.6	4.9	95.1	434.702	32

	Ecoregion	Area (1,000 ha)	Protected Area (%)	Share of Land where Natural Processes Predominate (%)	Share of Land where Natural Processes Predominate that is Protected (%)	Share of Land where Natural Processes Predominate that is Unprotected (%)	Cropland (1,000 ha)	Share of Cropland with at > 10% natural vegetation within 1km²(%)
559	Trans-Mexican Volcanic Belt pine-oak forests	9250.213	17.8	25.1	25.1	74.9	2408.496	38.5
550	Veracruz dry forests	663.957	4.7	50.7	0.2	99.8	382.475	40.9
514	Veracruz moist forests	6900.271	7.6	12.6	41.3	58.7	3837.916	27.9
515	Veracruz montane forests	496.771	6.2	28.2	5.9	94.1	17.735	98.4
384	Western Gulf coastal grasslands	1523.11	18.2	5.5	79.3	20.7	935.359	18.4
551	Yucatán dry forests	4981.967	9.6	41.8	13.5	86.5	451.731	74.7
519	Yucatán moist forests	6949.908	23.5	71.7	31.1	68.9	298.449	74.5

Sources: countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); cropland, natural and semi-natural vegetation – ESA CCI land cover 2015 (ESA, 2017); protected areas – UNEP-WCMC and IUCN (2020); natural processes predominate comprises key biodiversity areas – BirdLife International 2019, intact forest landscapes in 2016 – Potapov et al. (2016), and low impact areas – Jacobson et al. (2019)

Nature Map

In 2005, following the Millennium Ecosystem Assessment, Mexico launched a national effort to assess the state of knowledge, the status of the components, and the function of biodiversity, and approaches to its conservation and management. The Mexican National Commission on Biodiversity (CONABIO) was in charge of this effort with the purpose of guiding policy related to the use, conservation and management of Mexico's biodiversity. During the same period, the Mexican National Forestry Commission (CONAFOR) generated a map of aboveground carbon storage created in Mexico. The data for this map was generated from empirical modeling on forest inventory and remote sensing data collected from 2004 to 2007. These efforts have created a wealth of spatially explicit data that has been used to identify priority areas for conservation and restauration.

In this preliminary study, we tested a spatial optimization tool that would identify areas that should be managed for conservation meanwhile generating the greatest synergies between biodiversity and ecosystem services. This effort is necessary because despite substantial achievements and almost 17% of Mexico's terrestrial area under protection, the pace of ecosystem degradation and biodiversity loss in Mexico is unacceptable.

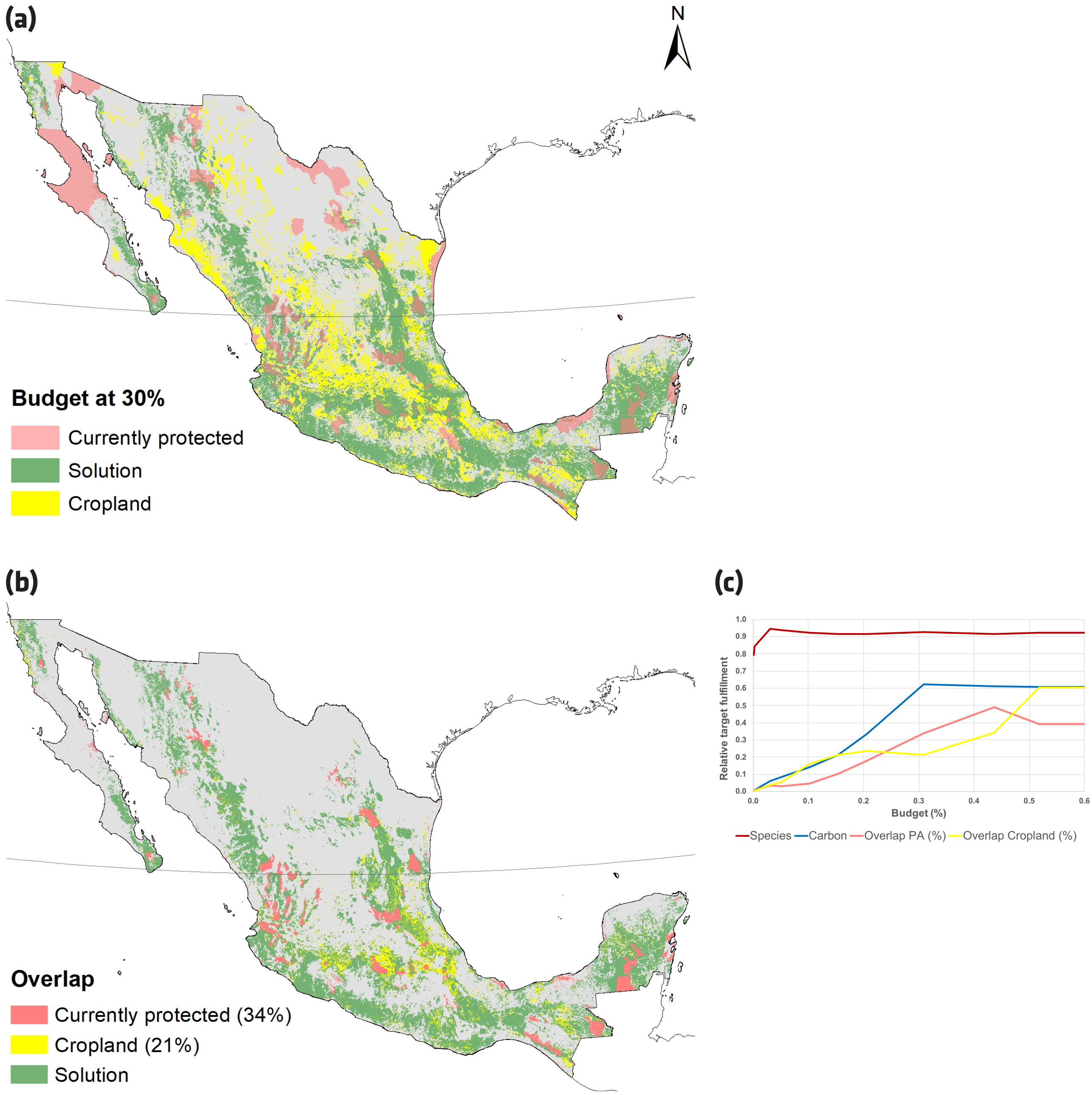
For this preliminary study, we considered all known terrestrial vertebrate species with a conservation status included in one of the following lists: the Mexican list of wild species or species populations at risk (NOM 059), the International Union for Conservation of Nature (IUCN) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). For the ecosystem services in terms of carbon storage we used the spatially explicit map of aboveground carbon storage created by CONAFOR. CONABIO's database provided with 322 species distribution range spread across 24 ecoregions. We divided the entire country in planning units of 4km2 and stablished a conservation target of 40% of the species distribution range independently of their conservation status and 60% of aboveground biomass carbon. We generally followed Nature Map methodology to chart the variables against protection budgets (from 0 to 100% of terrestrial country area) to reach the desired conservation targets.

An initial solution for the optimization problem is shown in figures 11a and 11c. The map shows the optimal amount of area to preserve up to 92% of the selected species and 62% of all aboveground carbon biomass with a budget of 30% of Mexico's terrestrial area. Given that carbon biomass is unevenly distributed in Mexico, mainly located along the Sierras crisscrossing the country and in the southeast humid tropical region, the synergies between carbon and biodiversity benefit areas with high carbon biomass, rich in endemism, and water provision (mountains). The results show the potential to achieve protection for the most vulnerable species in Mexico while protecting ecosystem services that are of outmost importance for a country that has two thirds of its territory in arid and semiarid ecosystems.

Figures 11b-c show in red and yellow the overlap of the solution with current protected areas and cropland. The overlap with cropland would mean that 21% of the agricultural area would be impacted if the proposed solution were implemented. Considering the most current data on crop production and its spatial distribution the economic loss would correspond to 35% of the value of the total crop production for 2016/2017.

The solution given with a 30% budget should be improved because despite having a high percentage of species represented in this initial solution, only 16% of them have at least 40% of their distribution range represented. Furthermore, crop loss of 35% would negatively impact Mexico's food security strategy for the short and medium term. Future optimizations should be carried out with all the available species to increase the number of species and its distribution range while keeping important food production areas with minimal impact. Integrating agrobiodiversity and agricultural areas at the same time as biodiversity and ecosystem services might help to achieve what seems to be contrasting objectives: food security and conservation of natural resources. Mexico already has ample legal tools that make possible the integration of food production and environmental conservation in the same area.

Figure 11 | Prioritization analysis. (a) Map of the solution for a 30% terrestrial area budget. (b) Map of overlapping features, current protected areas and cropland. (c) Calculation of the relative target fulfillment for different sets of features, as a function of the allowed budget: (a) biodiversity (mammals, herps, birds, and amphibian's species with conservation status), aboveground carbon biomass and overlap with current protected areas and cropland.



Units

°C – degree Celsius

% – percentage

/yr – per year

cap – per capita

CO_2 – carbon dioxide

CO_2e – greenhouse gas expressed in carbon dioxide equivalent in terms of their global warming potentials

g – gram

GHG – greenhouse gas

ha – hectare

kcal – kilocalories

kg – kilogram

km^2 – square kilometer

km^3 – cubic kilometers

kt – thousand tons

m – meter

Mha – million hectares

Mm^3 – million cubic meters

Mt – million tons

t – tonne

TLU – Tropical Livestock Unit is a standard unit of measurement equivalent to 250 kg, the weight of a standard cow

t/ha – tonne per hectare, measured as the production divided by the planted area by crop by year

t/TLU, kg/TLU, t/head, kg/head- tonne per TLU, kilogram per TLU, tonne per head, kilogram per head, measured as the production per year divided by the total herd number per animal type per year, including both productive and non-productive animals

USD – United States Dollar

W/m^2 – watt per square meter

yr – year

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